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(54) **METHOD AND APPARATUS FOR AUTO-ADJUSTING ILLUMINATION**

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(60) Provisional application No. 60/142,999, filed on Jul. 8, 1999.

(51) **Int. Cl.**
G01B 11/00 (2006.01)

(52) **U.S. Cl.** **356/394**

(58) **Field of Classification Search** 356/394; 348/370, 131; 382/141; 362/85, 89
See application file for complete search history.

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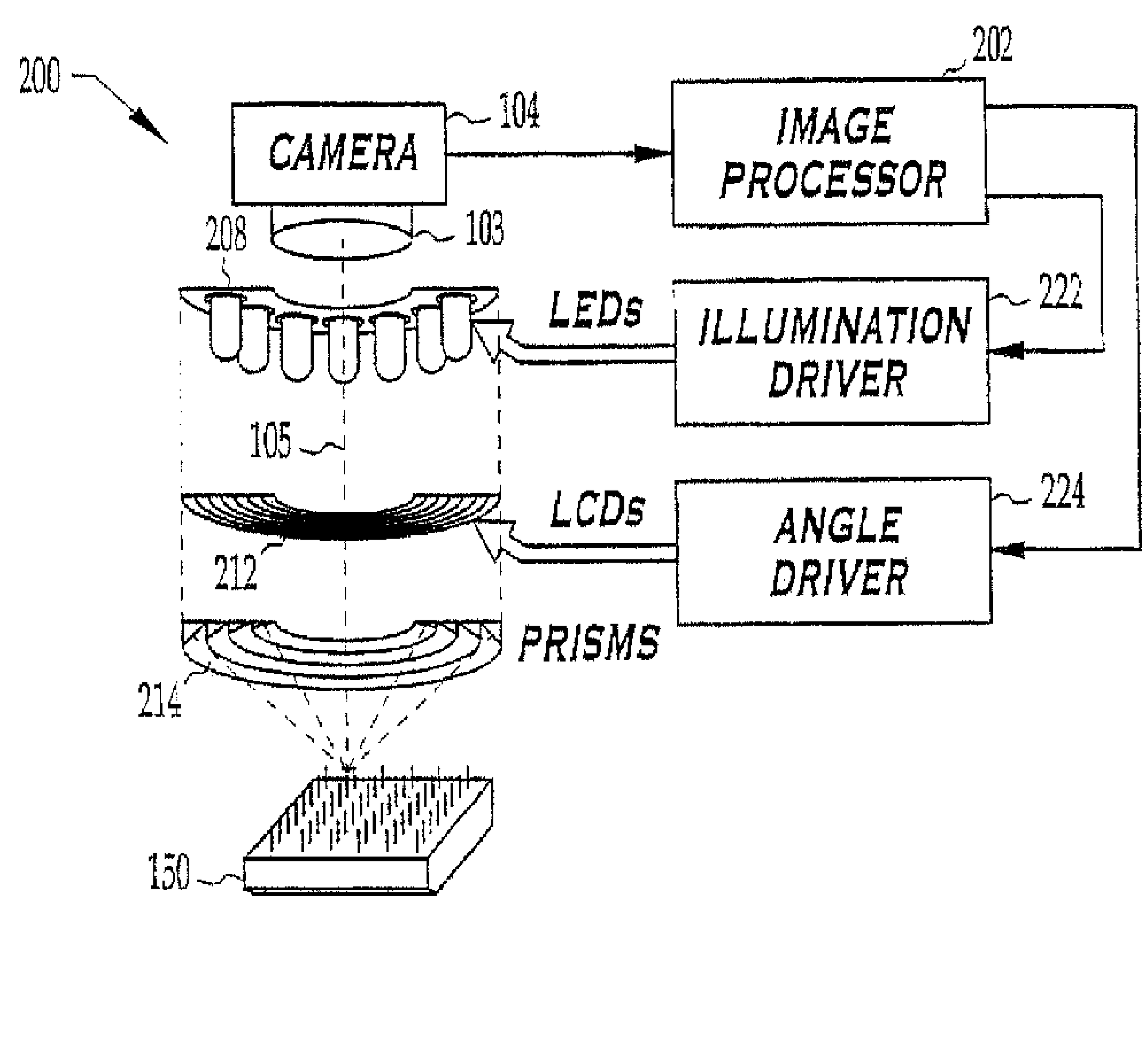
(57) **ABSTRACT**

A machine-vision system that provides changing and/or automatic adjustment of illumination angle, dispersion, intensity, and/or color of illumination. One such system includes a light source emitting polarized light, a machine-vision imager, an image processor operative to generate a quality parameter based on the image, and one or more of the means described above for selectively directing the light in a predetermined pattern based on its polarization and on the quality parameter of the image. Some embodiments include an imager, a controllable light source, first and second optical elements, that selectively direct light in first and second patterns, and a controller controlling the light characteristics using the first and second light patterns. One method includes setting one or more illumination parameters, illuminating the object based on the illumination parameters, obtaining an image, generating a quality parameter based on a region of interest, and iterating using different illumination parameters.

19 Claims, 4 Drawing Sheets



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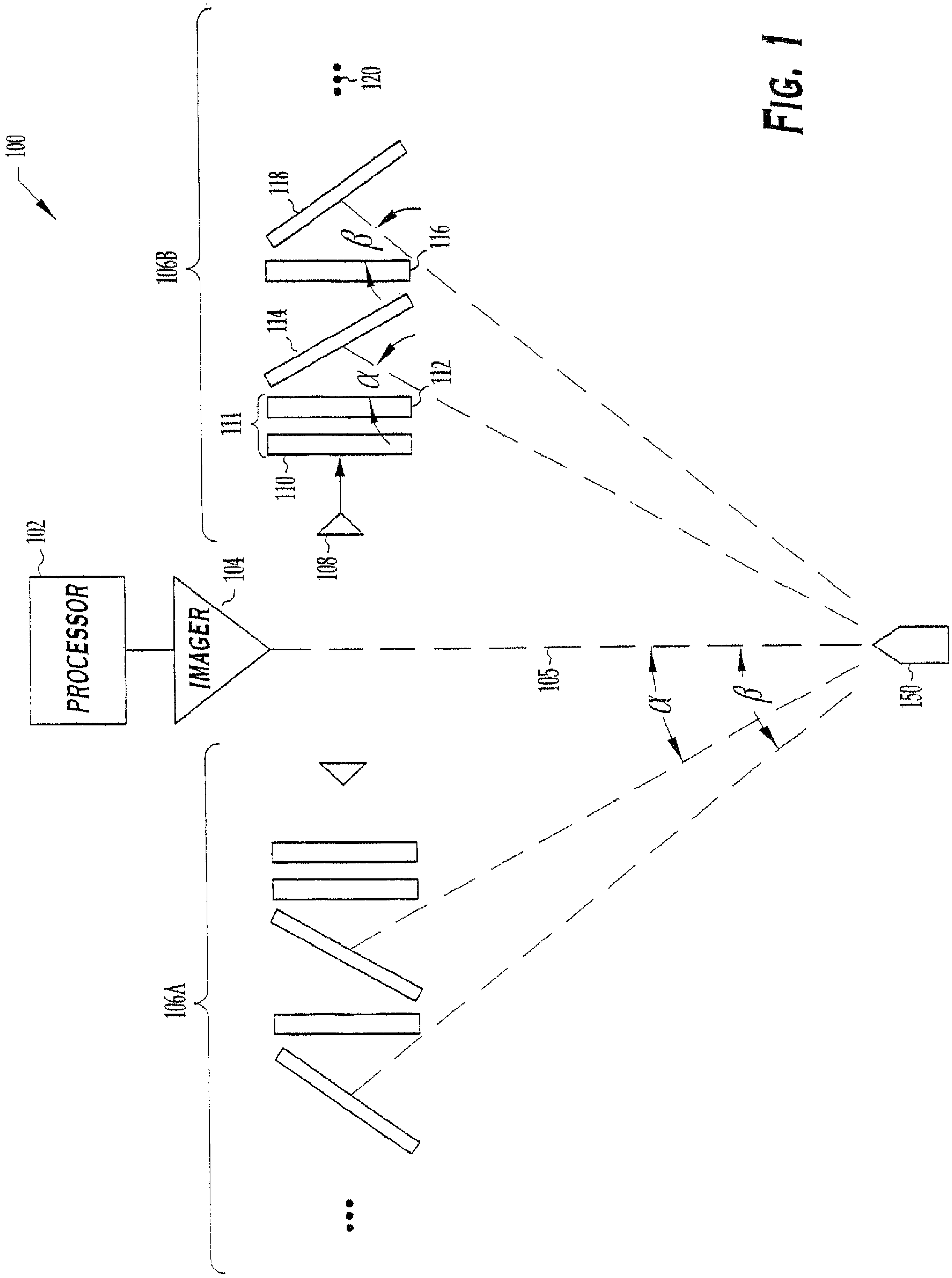
100
PROCESSOR
102
IMAGER
104
105
106A
106B
108
110
111
112
114
116
118
120
150
α
β

FIG. 1

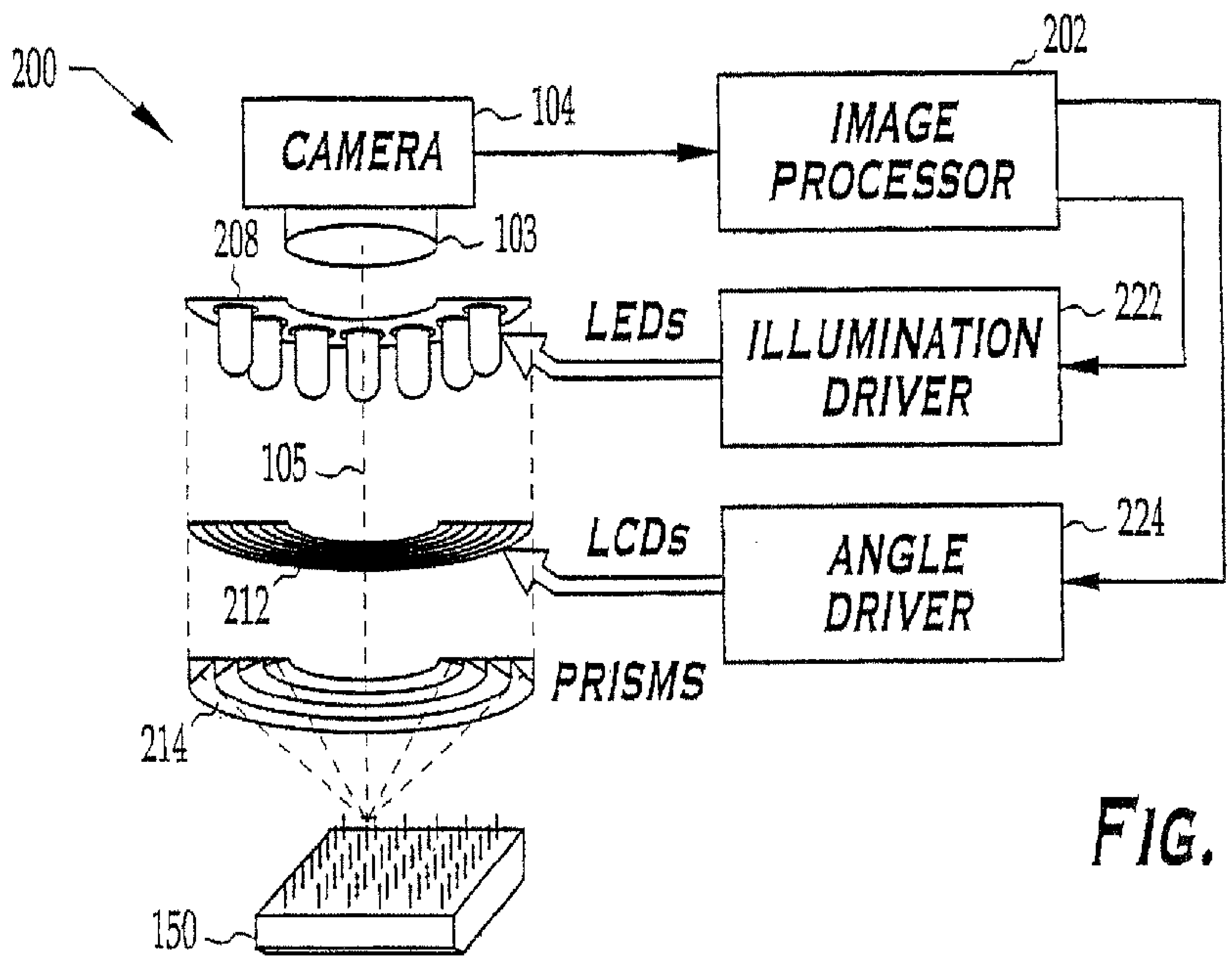
200
CAMERA
104
IMAGE PROCESSOR
202
103
208
LEDs
ILLUMINATION DRIVER
222
105
LCDs
ANGLE DRIVER
224
212
PRISMS
214
150

FIG. 2

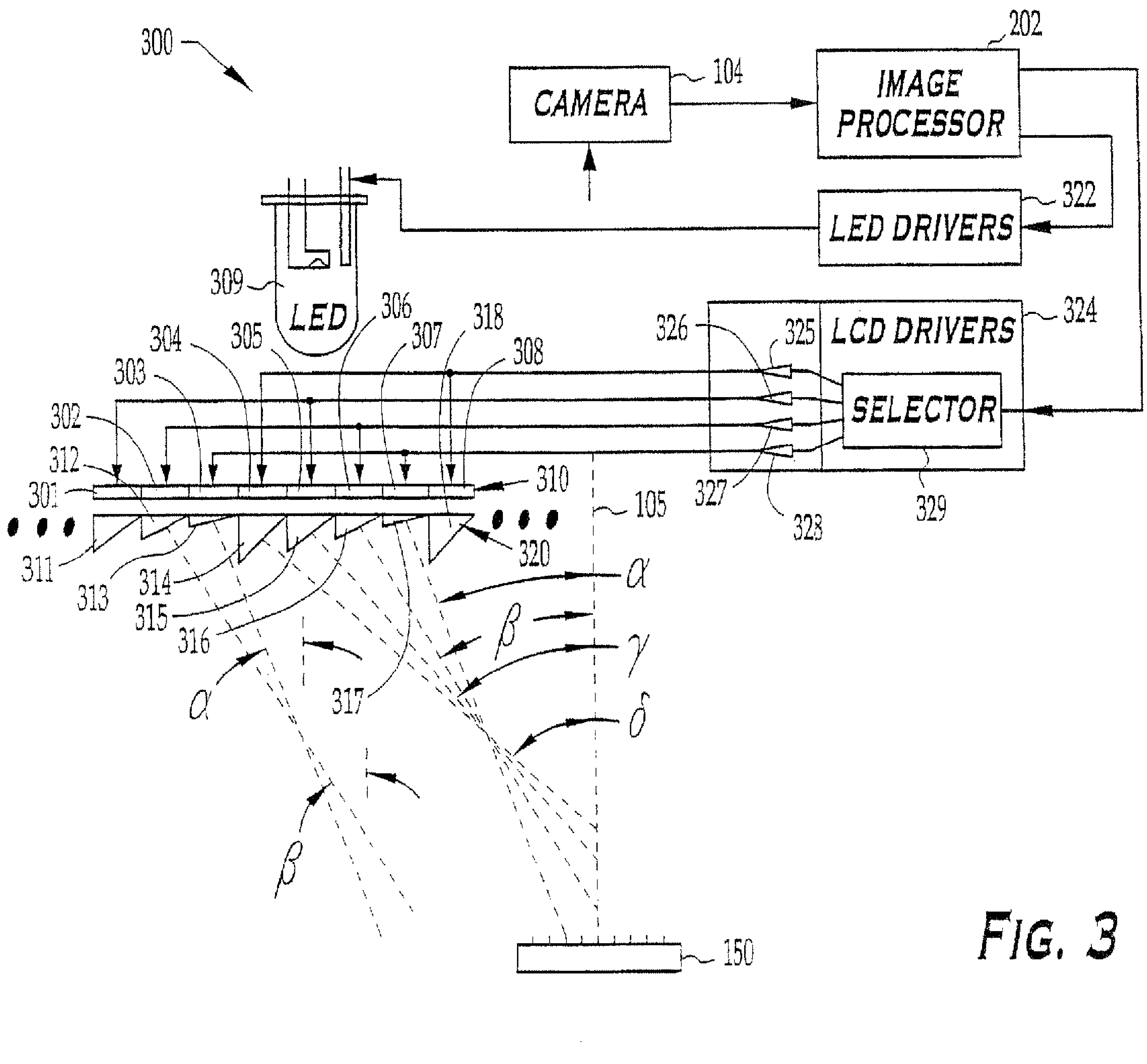
300
CAMERA
104
IMAGE PROCESSOR
202
LED DRIVERS
322
309
LED
LCD DRIVERS
324
SELECTOR
301
302
303
304
305
306
307
308
310
311
312
313
314
315
316
317
318
320
325
326
327
328
329
105
α
β
γ
δ
150

FIG. 3

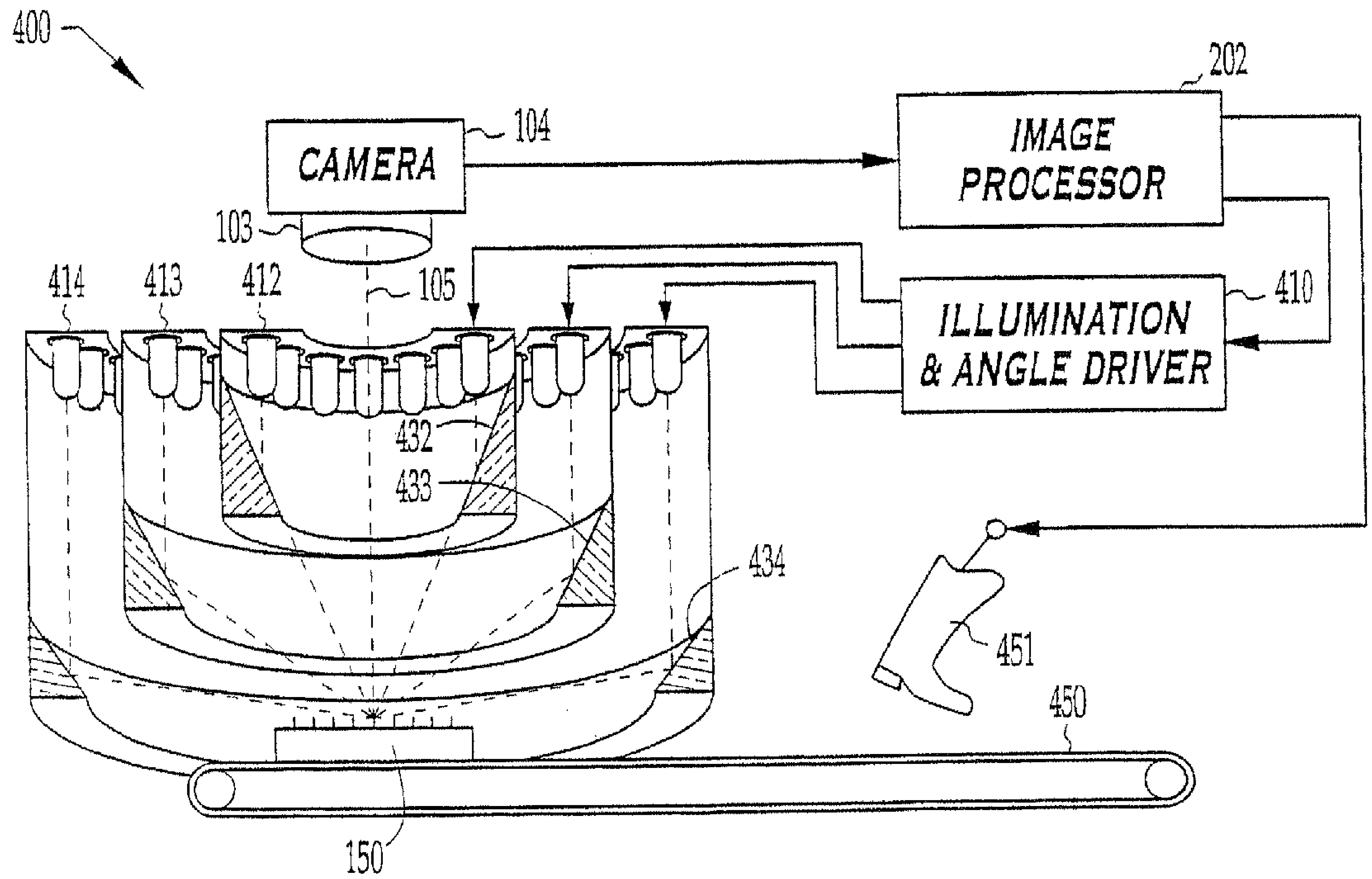
400
CAMERA
104
103
105
IMAGE PROCESSOR
202
ILLUMINATION & ANGLE DRIVER
410
414
413
412
432
433
434
451
450
150

FIG. 4

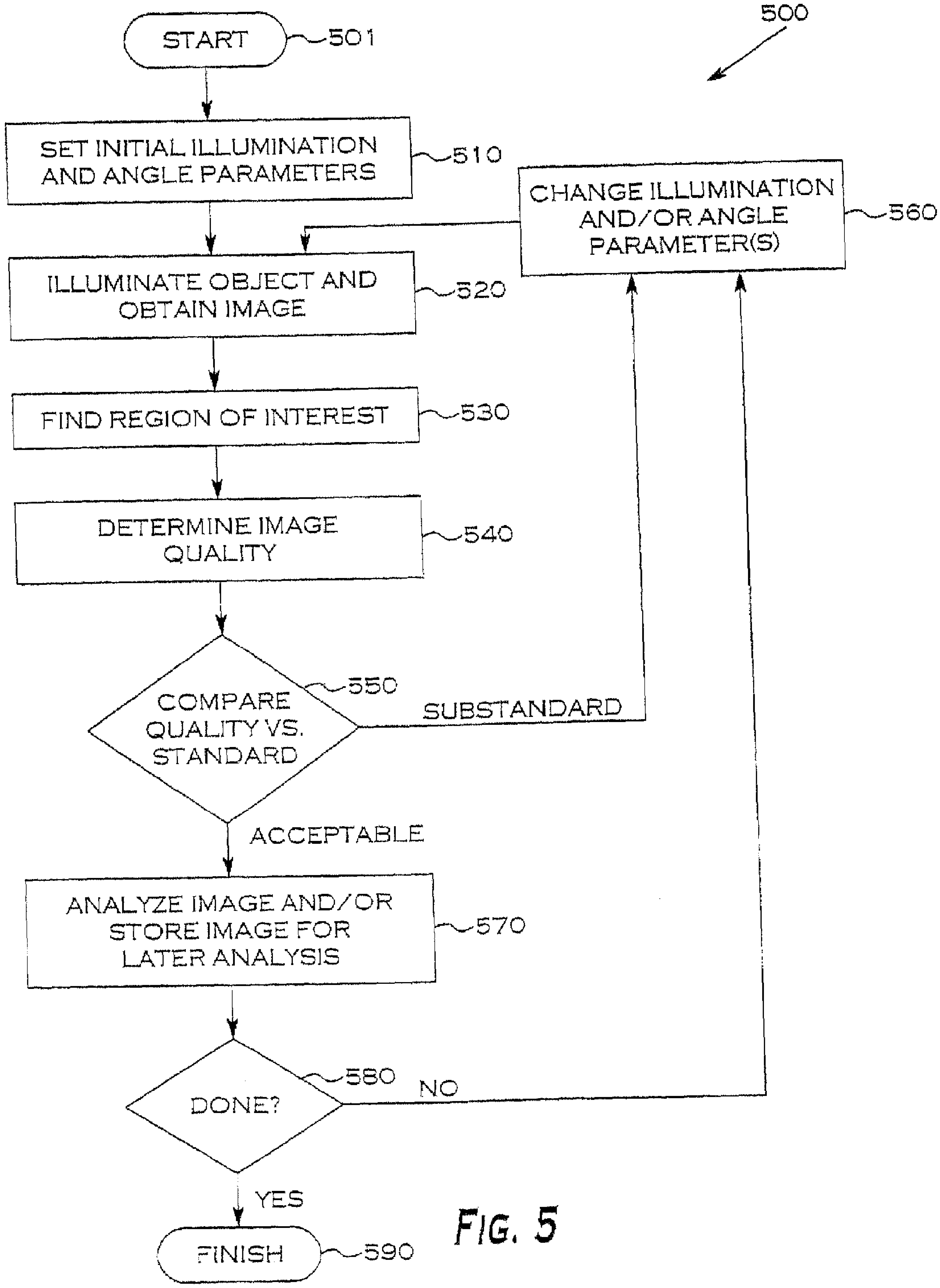
500
START
501
SET INITIAL ILLUMINATION AND ANGLE PARAMETERS
510
CHANGE ILLUMINATION AND/OR ANGLE PARAMETER(S)
560
ILLUMINATE OBJECT AND OBTAIN IMAGE
520
FIND REGION OF INTEREST
530
DETERMINE IMAGE QUALITY
540
COMPARE QUALITY VS. STANDARD
550
SUBSTANDARD
ACCEPTABLE
ANALYZE IMAGE AND/OR STORE IMAGE FOR LATER ANALYSIS
570
DONE?
580
NO
YES
FINISH
590

FIG. 5

METHOD AND APPARATUS FOR AUTO-ADJUSTING ILLUMINATION

CROSS-REFERENCE TO RELATED APPLICATIONS

This is a divisional under 37 C.F.R. 1.53(b) of U.S. patent application Ser. No. 10/903,753 (which issues Nov. 28, 2006 as U.S. Pat. No. 7,142,301) titled "METHOD AND APPARATUS FOR ADJUSTING ILLUMINATION ANGLE," filed Jul. 30, 2004; which is a divisional of U.S. patent application Ser. No. 09/612,763, filed Jul. 10, 2000 (now U.S. Pat. No. 6,788,411, issued Sep. 7, 2004), titled "METHOD AND APPARATUS FOR ADJUSTING ILLUMINATION ANGLE," and which claims benefit of U.S. Provisional Patent Application No. 60/142,999, filed Jul. 8, 1999; each of which is incorporated herein by reference.

This invention is also related to:

- U.S. Pat. No. 6,603,103 to Ulrich et al., titled "CIRCUIT FOR MACHINE-VISION SYSTEM", filed Jul. 8, 1999;
- U.S. patent application Ser. No. 09/350,050, titled "MACHINE-VISION SYSTEM AND METHOD FOR RANDOMLY LOCATED PARTS" (now abandoned), filed Jul. 8, 1999;
- U.S. patent application Ser. No. 09/350,255, titled "PARTS MANIPULATION AND INSPECTION SYSTEM AND METHOD" (now abandoned), filed Jul. 8, 1999;
- U.S. patent application Ser. No. 09/349,684, titled "MACHINE-VISION SYSTEMS AND METHODS WITH UP AND DOWN LIGHTS" (now abandoned), filed Jul. 8, 1999;
- U.S. patent application Ser. No. 09/349,948, titled "IDENTIFYING AND HANDLING DEVICE TILT IN A THREE-DIMENSIONAL MACHINE-VISION IMAGE" (now abandoned), filed Jul. 8, 1999;
- U.S. Pat. No. 6,522,777 to Paulsen et al., titled "COMBINED 3D- AND 2D-SCANNING MACHINE-VISION SYSTEM AND METHOD", filed Jul. 8, 1999;
- U.S. patent application Ser. No. 09/350,037, titled "PARTS MANIPULATION AND INSPECTION SYSTEM AND METHOD" (now abandoned), filed Jul. 8, 1999;
- U.S. patent application Ser. No. 09/350,251, titled "TRAY FLIPPER AND METHOD FOR PARTS INSPECTION", filed Jul. 8, 1999;
- U.S. Pat. No. 6,509,559 to Ulrich et al., titled "BINARY OPTICAL GRATING AND METHOD FOR GENERATING A MOIRE PATTERN FOR 3D IMAGING", filed Jun. 20, 2000;
- U.S. Pat. No. 6,486,963 to Holec, titled "PRECISION 3D SCANNER BASE AND METHOD FOR MEASURING MANUFACTURED PARTS", filed Jun. 20, 2000;
- U.S. Pat. No. 6,501,554 to Hackney et al., titled "3D SCANNER AND METHOD FOR MEASURING HEIGHTS AND ANGLES OF MANUFACTURED PARTS", filed on Jun. 20, 2000;

which were initially all assigned to a common assignee, and each of which is incorporated herein by reference.

FIELD OF THE INVENTION

The present invention generally concerns machine-vision, particularly systems and methods for lighting/illuminating objects in machine-vision systems.

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BACKGROUND OF THE INVENTION

There is a widespread need for inspection data for electronic parts in a manufacturing environment. Machine-vision systems have become vital to many complex manufacturing processes, particularly for quality control. For example, during the manufacture of integrated circuits which contain millions of transistors and other electrical components, machine-vision systems visually inspect the circuits at various manufacturing stages for surface blemishes or other defects, rejecting or accepting circuits based on appearance.

Machine-vision systems typically include an imaging device, such as an electronic camera and an illumination system, which illuminates an object for the camera. The typical illumination system, generally designed to illuminate all sides of an object simultaneously, comprises some form of a circular ring of lights, for example a ring-shaped flashtube, a ring of light-emitting diodes, or a ring of optical fibers. The circular ring of lights usually lies between the camera and object, with the camera looking down through the ring to the object and the lights oriented down and inward to the object.

Conventional illumination systems suffer from at least two major problems. First, they lack a convenient way for varying the angle of illumination, that is, the angle light strikes an object. Conventional illumination systems require technicians to manually adjust orientation of the complete ring of lights or to manually adjust orientation of its individual lights. However, manual adjustments are not only time consuming, but often lead to angular variations which compromise consistency of machine-vision systems. Second, conventional systems lack convenient way of switching from one illumination mode to another, for example, from a particular selected angle of illumination to a multi-directional object illumination, such as "cloudy-day illumination." Some select-angle illumination modes are better for viewing scratches, while cloudy-day illumination is better for specular or irregular surfaces. This lack of a convenient way of switching illumination modes often leads to use of more than one machine-vision system, and thus forces manufacturers to buy separate systems, to use human inspectors, or to skip inspection for some types of defects. Accordingly, there is a need for better illumination systems for machine-vision systems.

SUMMARY OF THE INVENTION

In the context of a machine-vision system for inspecting a part, this invention includes method and apparatus to provide high-speed changing and/or automatic adjustment of illumination angle, dispersion, intensity, and/or color of illumination in a machine vision system.

One aspect of the present invention provides a machine-vision system having an optical axis. This system includes a light source emitting light having a polarization, a machine-vision imager that obtains an image of an object illuminated by the light, a processor coupled to receive an image from the imager, and operative to generate a quality parameter based on the image, and one or more of the various means as described above for selectively directing the light in a predetermined pattern based on its polarization and based on the quality parameter of the image.

Another aspect of the present invention provides a machine-vision system having an optical axis. This system includes a machine-vision imager located along the optical axis, a controllable light source, a first optical element that selectively directs light in a first predetermined pattern relative to the optical axis based on light characteristics, a second optical element, that directs light in a second predetermined pattern relative to the optical axis, and an electronic controller operatively coupled to the imager and the controllable light source to control the light characteristics and thereby selecting one or more of the first and second predetermined patterns.

Another aspect of the present invention provides an illumination method that includes emitting light, selectively polarizing the light, and selectively directing the light based on its polarization.

In some embodiments, the selectively directing provides two or more different angles of illumination (e.g., alpha and/or beta). In some such embodiments, the angle is a conical angle of a ring illumination.

Yet another aspect of the present invention provides a machine-vision method for inspecting an object. This method includes (a) setting one or more illumination parameters, (b) illuminating the object based on the one or more illumination parameters, (c) obtaining an image of the illuminated object, (d) generating a quality parameter based on an image quality of a predetermined region of interest in the image, and (e) iterating (b), (c), and (d) using a different illumination parameter. In some embodiments of this method, the iterating is based on the quality parameter. In some embodiments, the one or more illumination parameters include a predetermined azimuth angle of illumination. In some embodiments, the one or more illumination parameters include a predetermined compass angle of illumination. In some embodiments, the one or more illumination parameters include a predetermined compass angle of illumination.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** shows a cross-section side-view schematic of an embodiment of the present invention, an electronically-controlled variable-angle machine-vision illumination system **100**.

FIG. **2** shows a cut-away side-view schematic of another embodiment of the present invention, an electronically-controlled variable-angle machine-vision illumination system **200**.

FIG. **3** shows a cut-away side-view schematic of yet another embodiment of the present invention, an electronically-controlled variable-angle machine-vision illumination system **300**.

FIG. **4** shows a cut-away side-view schematic of yet another embodiment of the present invention, an electronically-controlled variable-angle machine-vision illumination system **400**.

FIG. **5** shows a flowchart schematic of yet another embodiment of the present invention, an electronically-controlled variable-angle machine-vision illumination method **500**.

DETAILED DESCRIPTION OF THE INVENTION

In the following detailed description of the preferred embodiments, reference is made to the accompanying drawings which form a part hereof, and in which are shown by way of illustration specific embodiments in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present invention.

Machine-vision and optical-feature-recognition techniques can be used to distinguish parts that deviate from a predetermined intended aspect of an ideal device. In this description, a "device" is meant to be any part, device of manufacture or object, for example an integrated circuit package, electronic part, semiconductor, molded plastic part, aluminum wheel, gemstone or even an egg or strawberry, which can be inspected. Typically, according to the present invention, a manufacturing operation will use geometric information about the parts acquired from machine-vision inspection of the device to distinguish "good" devices from "bad" devices, and can discard the bad devices and insert previously inspected good devices in their place, for example to obtain a tray of all-good devices. In some embodiments, the devices under test are placed into pocketed trays or into cartons for ease of handling and transport, and inspection will take place of the devices while the devices are in the pocketed trays, according to the present invention. In other embodiments, a parts holder having a clamping mechanism is used to hold a plurality of parts, such as disk suspensions, to an inspection-station fixture.

FIG. **1** shows a cross-sectional block diagram of an exemplary machine-vision system **100** embodying teachings and principles of the present invention. System **100** includes an analog or digital processor **102**, an analog or digital imager **104** having an optical axis **105**, and a symmetric illumination system **106** (including left and right halves **106***a* and **106***b*) that illuminates object **150** at selectable angles α and β relative to axis **105**. Each half (**106***a* and **106***b*) of illumination system **106** includes a light source **108**, a polarizer **110**, a first liquid-crystal panel **112**, a first polarized reflector **114**, a second liquid-crystal panel **116**, and a second polarized reflector **118**. (The ellipsis **120** indicates that the exemplary embodiment includes further liquid-crystal panels and corresponding polarized reflectors.)

In operation, light source **108** emits light to polarizer **110**, which polarizes the light in a select direction. Polarized light exits to liquid-crystal panel **112** which may or may not alter the polarization of the polarized light, depending on applied electrical stimulus. Light exiting panel **112** is reflected by or transmitted through polarized reflector **114** depending on its polarization. Reflector **114** is oriented to reflect appropriately polarized light toward object **150** at a first predetermined angle α relative to axis **105**.

Light that is not polarized for reflection by reflector **114** passes to second liquid-crystal panel **116** which with appropriate electrical stimulus changes polarization of incoming light. Light exiting panel **116** strikes polarized reflector **118**, which reflects or transmits it, based on its polarization. Reflector **118** is oriented to reflect appropriately polarized light toward object **150** at a second predetermined angle β relative to axis **105**.

Thus, using a light source, and one or more sets of electrically controllable polarizers and polarized reflectors, one can select various angles of illumination for objects in a machine-vision system. Thus, without physically changing optical components, one can quickly and easily change the illumination angle to obtain images that improve contrast and/or clarity of features of interest on object **150**. In some cases, highly reflective or specular features can be better imaged if the light is at a particular angle that either enhances or suppresses reflections from such surfaces to the camera **104**. In other cases, fine machining marks (e.g., polishing lines) will show clearly if the light is at a particular angle, and depending on whether the user wants to enhance or suppress such marks on the image, a different angle will be chosen.

In some embodiments, optical element **110** and optical element **112** together combine to form an electrically controllable polarizer **111**, wherein the angle of polarization can be electronically controlled by processor **102**. Thus, if controllable polarizer **111** sets a first angle of polarization that matches that which is reflected by polarized reflector **114**, then illumination angle alpha (α) is obtained. On the other hand, if the angle of polarization generated by controllable polarizer **111** matches that which is transmitted by polarized reflector **114**, then, in some embodiments (i.e., those that omit LCD **116** and have reflector **118** totally reflecting), the transmitted light is reflected by reflector **118** with illumination angle beta (β). In other embodiments that include LCD **116**, the polarizer **110**, LCD **114** and LCD **116** together form an electronically controllable polarizer for the light directed to reflector **118** (and optionally further elements **120**).

In some embodiments, illumination source **106** is circularly symmetric, having a ring light source **108**, a ring polarizer **110**, a ring liquid-crystal device (LCD) **112**, a conical section angled polarized reflector/transmitter **114**, a second ring LCD **116**, and a second conical section angled polarized reflector/transmitter **114**. In some embodiments, further pairs of LCDs and angled reflectors (shown as ellipses **120**) are included. In some embodiments, LCD **116** is omitted for the outermost ring, and reflector **118** is maximally reflective for all incident light. In other embodiments, further polarizers **116** and reflectors **118** are included to provide yet other angles of illumination light. In some embodiments, each ring or conical section is centered about optical axis **105**. In such embodiments, selectable illumination angles α and β are conical angles relative to the optical axis **105** that represent the conical surface that the illumination is centered about. In some such embodiments, light source **108** is one or more rows of light-emitting diodes (LEDs) mounted facing radially outward on a cylindrical surface. In some embodiments, the LEDs of light source **108** are divided into banks, wherein each bank is separately driven (e.g., eight banks, wherein each bank represents a forty-five-degree section of the ring, for example the eight compass directions N, NE, E, SE, S, SW, W, and NW—wherein compass angle is defined as an angle in a direction circumferential to the optical axis), allowing further selection of the compass angle using the LED drivers, as well as the azimuth angle selected by the LCDs and polarized reflector(s) as described above.

In some embodiments, banks of LEDs are organized such that different banks have different colors of light. In some such embodiments, an image is obtained at each of a plurality of colors, the quality of the images is determined by image processor **202**, and the color (or combination of colors) that yields the best image is used.

In some embodiments, banks of LEDs are organized such that different banks have different dispersion angles light (e.g., using LEDs having different emission angles). In some such embodiments, an image is obtained at each of a plurality of dispersion angles, the quality of the images is determined by image processor **202**, and the parameter that yields the best image is used.

In some embodiments, banks of LEDs are organized such that different banks have different colors of light. In some such embodiments, an image is obtained at each of a plurality of colors, the quality of the images is determined by image processor **202**, and the color that yields the best image is used.

In other embodiments, each component of FIG. **1** is a straight plane extending into the drawing sheet, such that illumination source **106** includes two linear halves, each having a straight-line or plane light source **108**, a plane polarizer **110**, a plane liquid-crystal device (LCD) **112**, a plane angled polarized reflector/transmitter **114**, a second plane LCD **116**, and a second plane angled polarized reflector/transmitter **114**. In some embodiments, further pairs of LCDs and angled reflectors (shown as ellipses **120**) are included. In some embodiments, for the outermost section, LCD **116** is omitted and reflector **118** reflects all incident light.

In yet other embodiments, each component of FIG. **1** is a straight plane section of a polygon centered about optical axis **105**, such that illumination source **106** includes a plurality of sections, each having a straight-line or plane light source **108**, a plane polarizer **110**, a plane liquid-crystal device (LCD) **112**, a plane angled polarized reflector/transmitter **114**, a second plane LCD **116**, and a second plane angled polarized reflector/transmitter **114**. In some embodiments, further pairs of LCDs and angled reflectors (shown as ellipses **120**) are included. In some embodiments, for the outermost section, LCD **116** is omitted and reflector **118** reflects all incident light.

FIG. **2** shows a cut-away side-view schematic of another embodiment of the present invention, an electronically-controlled variable-angle machine-vision illumination system **200**. In some embodiments, illumination system **200** includes a flat ring light source **208** having one or more concentric rows of LEDs, a flat ring liquid-crystal device **212**, and a concentric angular refraction element **214** that includes concentric Fresnel groves concentric prisms, or a concentric hologram. The ring LCD **212** includes a plurality of separately drivable LCD ring patterns, each driven by LCD angle driver **224**, such that one or more concentric rings is transparent to the light from light source **208**, while other concentric rings of LCD **212** are opaque or reflective to the incident illumination. Thus, in some embodiments, each ring of prisms **214** (or Fresnel grooves or holographic deflector rings) refracts the light incident to it at a different conical angle, and the rings of LCD **212** select which ring of prism **214** will get light. One or more of the concentric LCD rings of **212** are dedicated to each of the plurality of conical angles that may be illuminated, and one or more of the conical angles may be activated simultaneously. This allows angle driver **224** to select which azimuth angle or angles of illumination will be activated. In some embodiments, one or more concentric rings of LCD **212** will be driven to be in a substantially transparent state, and zero or more other rings of LCD **212** will be driven to be in a substantially reflective state, and the substrate of light source **208** (i.e., the surface under and around the LEDs) is made reflective, such that the light reflected by LCD rings in a reflective state has another chance to go through those ring sections that are transparent to be sent to device **150** at the desired angle(s).

In some embodiments, illumination driver **222** provides a short pulse of current to all the LEDs at once (e.g., providing a cone of illumination or illumination centered on one or more conical sections). In some embodiments, illumination driver **222** includes drivers such as described in U.S. patent application Ser. No. 09/349,684, entitled "MACHINE-VISION SYSTEMS AND METHODS WITH UP AND DOWN LIGHTS," filed Jul. 8, 1999, and/or U.S. Pat. No. 5,745,176 entitled "MACHINE VISION ILLUMINATION SYSTEM AND METHOD" issued Apr. 28, 1998 (both incorporated by reference). In some other embodiments, the LEDs of light source **208** are divided into banks, wherein each bank is separately driven by illumination driver **222** (e.g., eight banks, wherein each bank represents a forty-five-degree section of the ring, for example the eight compass directions N, NE, E, SE, S, SW, W, and NW), allowing further selection of the compass angle of illumination using the LED drivers, as well as the azimuth angle selected by the LCDs **212** and refractor ring(s) as described above.

FIG. **3** shows a cut-away side-view schematic of yet another embodiment of the present invention, an electronically-controlled variable-angle machine-vision illumination system **300**. In some embodiments, system **300** represents a detailed view of system **200** of FIG. **2**. Thus, in these embodiments, LCDs **310** include a plurality of concentric ring LCD areas (shown are rings **301**, **302**, **303**, **304**, **305**, **306**, **307**, and **308**), each ring area driven by one of the drivers **324**. In the embodiment shown, selector **329** selects one or more individual drivers **325**, **326**, **327**, and/or **328**. Driver **325** drives LCD ring sections **304** and **308**; driver **326** drives LCD ring sections **301** and **305**; driver **327** drives LCD ring sections **302** and **306**; driver **328** drives LCD ring sections **303** and **307**. In some embodiments, further concentric rings are added to each of these four sets. In other embodiments, more or fewer sets are provided, and more or fewer LCD areas are included in each set. Since LCD drivers **324** can drive one or more LCD sets, one or more angles selected from the four angles alpha, beta, gamma, and delta (α, β, γ, and δ) can be illuminated at one time. In embodiments that are circularly symmetric, these are conical angles to the optical axis **105**. In some embodiments, LED drivers **322** drive LED light source **309** in one or more banks, as described above for illumination driver **222** of FIG. **2**.

In other embodiments, FIG. **3** represents a linear (i.e., straight line) illumination source, one or more of which are implemented at selected compass angles around object **150** and optical axis **105**. In some such embodiments, light source **309** includes one or more rows of LEDs organized on one or more banks, similarly to the circular arrangement described above.

FIG. **4** shows a cut-away side-view schematic of yet another embodiment of the present invention, an electronically-controlled variable-angle machine-vision illumination system **400**. In some embodiments, system **400** includes camera **104** that provides images to image processor **202**, which drives illumination and angle driver **410** which drives concentric rings of LEDs **412**, **413**, and **414**. In some embodiments, angled ring reflectors **432**, **433**, and **434** provide steep, medium, and shallow conical reflections angles respectively. Ring **412** includes one or more concentric rows of LEDs, and when activated by driver **410**, provides a steep conical illumination to object **150** as reflected by reflector **432**. Similarly, ring **413** includes one or more concentric rows of LEDs, and when activated by driver **410**, provides a steep conical illumination to object **150** as reflected by reflector **433**; and ring **414** includes one or more concentric rows of LEDs, and when activated by driver **410**, provides a steep conical illumination to object **150** as reflected by reflector **434**.

Some embodiments further include a support station **450** (such as a conveyor belt) that supports an object being inspected by the machine vision system, and a selector **451** that rejects that object based on an analysis of the image.

In some embodiments (not shown), a variable-angle liquid-crystal reflector, such as available from Boulder Nonlinear Systems Incorporated (BNS), a privately held Colorado business located at 450 Courtney Way, #107 Lafayette, Colo. USA 80026, is used to provide electronically controlled beam reflection at various different angles. For example, in some embodiments, light from an array of LEDs is reflected off of an LCD reflective device such as a Boulder Nonlinear Systems Incorporated 1×4096 optical Beam Steering Array having 4096 pixels, and arranged as a reflective VLSI backplane in ceramic PGA carrier, and having an array size of 7.4×7.4 mm with a pixel size of 1 μm wide by 7.4 mm high and a pixel pitch of 1.8 μm. In some embodiments, a liquid crystalline mixture comprising nematic or chiral smectic liquid crystal active material is used. In some embodiments, this provides an optical modulation (analog) ~4 to 6 bits linear modulation levels providing a resolution of 225 different angles and steer angles of ±3.4 degrees (with light wavelength λ=1550 nm), and random selection of steer angle. In other embodiments, a liquid crystal refractor of similar design is used to replace the variable-angle mechanism **310** and **320** of FIG. **3**.

In various embodiments, image processor **202** of FIG. **2** or FIG. **3** or FIG. **4** obtains one or more images, each at a selected angle (conical angle and/or compass angle) of illumination, examines (e.g., using a computer program) one or more regions of interest to determine the quality of the image obtained, and based on a quality criterion, optionally changes the illumination angle(s) and obtains further images, in order to choose an illumination angle or angles that provide an acceptable image, such as described further below.

FIG. **5** shows a flowchart schematic of yet another embodiment of the present invention, an electronically-controlled variable-angle machine-vision illumination method **500**. In some embodiments, after start **501**, block **510** sets initial illumination and angle parameters (e.g., processor **202** (see FIG. **2**, **3**, or **4**) sets drive parameters to illumination driver **222**, **322**, or **410** and to angle drivers **224**, **324**, or **410**, for example setting the LED pulse width and current amount, selecting which LEDs will be driven, and/or selecting which LCD areas or rings will be made transparent or polarization angles that are set). Control passes to block **520**, where the object(s) **150** is/are illuminated, and an image is obtained (e.g., by imager **104**). Control passes to block **530**, where the region of interest in the image is located. Control passes to block **540**, where the quality of the image within the region of interest is determined (e.g., the contrast amount on certain pins of a pin-grid-array electronic device is checked to generate a quality parameter). Control passes to block **550**, where the quality parameter generated by block **540** is compared to a standard (e.g., to an absolute standard value for image quality, or relatively to quality parameters determined for other illumination angle(s), such as when multiple images are taken of an object **150** and compared one to the other(s) to determine which angle yields the "best" image). If, at block **550**, it is determined that the image is substandard (relative to an absolute quality standard) or that more images are needed to compare one to the others, then control passes to block **560** where the illumination and/or angle parameter(s) are changed, and the imaging blocks (**520**-**550**) are iterated. Once one or more acceptable images are obtained using the various azimuth angle illumination and compass-angle illumination parameters, control passes to block **570**, where the image obtained is analyzed and/or stored for further later analysis. Such machine-vision analysis is performed using any process well-known to those of skill in the art; and a determination is optionally made as to whether the quality of the object (e.g., manufactured part) is acceptable or not. If not acceptable, the part is rejected, and/or the manufacturing process is adjusted to generate more acceptable parts. In some embodiments, at block **580**, a determination is made as to whether more images are needed (if we are not done, control passes to block **560** to again change the illumination parameters as iterate through the above process), and if we are done, control passes to the finish **590**.

Other embodiments of the invention use a piezo-electric mechanism to vary the refractive properties of a ring lens, that is, a lens having a central hole or cutout. In this embodiment, the imager **104** peers through the hole in the ring lens to an object **150**. Another embodiment uses a liquid-crystal panel to vary the angle of reflection of a ring reflector.

In some embodiments, the present invention provides a machine-vision system having an optical axis, including a processor; an imager coupled to the processor; means for emitting light; means for selective polarizing the light; and means for selectively reflecting the polarized light in a predetermined direction relative to the optical axis based on its polarization.

In some embodiments, the present invention provides a machine-vision system including a processor; an imager coupled to the processor; at least one light source; at least one liquid-crystal panel proximate the one light source; and at least one reflector proximate the one liquid-crystal panel.

In some embodiments, the present invention provides a machine-vision system including a processor, an imager coupled to the processor, at least one light source for emitting light, at least one liquid-crystal panel proximate the one light source for selectively changing polarization of the light, and at least one selective reflector proximate the one liquid-crystal panel for selectively reflecting light from the liquid-crystal panel based on its polarization.

In some embodiments, the present invention provides apparatus including means for emitting light, means for selective polarizing the light, and means for selectively reflecting the polarized light in a predetermined direction based on its polarization.

In some embodiments, the present invention provides a machine-vision system having an optical axis, including a light emitter having a polarization, and an electrically activatable polarized reflector unit for selectively reflecting the light in a predetermined direction relative to the optical axis based on its polarization.

In some embodiments, the present invention provides an illumination method including emitting light, selectively polarizing the light, and selectively reflecting the light based on its polarization.

In some embodiments, the present invention provides a machine-vision system having an optical axis, including a light source, means for selectively directing light in a first predetermined direction relative the optical axis based on its polarization, and means for selectively directing light in a second predetermined direction relative to the optical axis based on its polarization.

One aspect of the present invention provides a machine-vision system **100** having an optical axis **105**. This system **100** includes a light source **108-110-112** emitting light having a polarization, a machine-vision imager **104** that obtains an image of an object illuminated by the light, a processor **102** coupled to receive an image from the imager, and operative to generate a quality parameter based on the image, and one or more of the various means as described above for selectively directing the light in a predetermined pattern based on its polarization and based on the quality parameter of the image.

In some embodiments, the means for selectively directing the light include a liquid-crystal device **112**. In some embodiments, the means for selectively directing the light further include a polarized reflector **114**.

Another aspect of the present invention provides a machine-vision system **100**, **200**, **300**, or **400** having an optical axis **105**. This system includes a machine-vision imager **104** located along the optical axis **105**, a controllable light source (**108-110-112**, **208-212**, **310**, or **412-413-414**), a first optical element (**114**, **214**, **311**, or **432**) that selectively directs light in a first predetermined pattern relative to the optical axis based on light characteristics, a second optical element (**118**, **214**, **312**, or **433**), that directs light in a second predetermined pattern relative to the optical axis, and an electronic controller **102** or **202**) operatively coupled to the imager **104** and the controllable light source to control the light characteristics and thereby selecting one or more of the first and second predetermined patterns.

In some embodiments, the controllable light source includes a light source (**108**), and a controllable polarizer (**111**) for setting a polarity of the light, wherein the electronic controller is operatively coupled to the controllable polarizer to control the light polarization characteristics and thereby selecting one or more of the first and second predetermined patterns.

In some such embodiments, the first optical element **114** includes a polarized reflector that reflects light polarized on one direction and transmits light polarized in another direction.

In some embodiments, the controllable light source includes a light source **208**, and a liquid crystal device (LCD) **212** having two or more areas that are each controllable to selectively transmit light.

In some embodiments, the first optical element includes a prism refractor **214** or **311** that refracts light in the first pattern when a first one of the two or more LCD areas transmits light.

In some embodiments, the second optical element includes a prism refractor **214** or **312** that refracts light in the second pattern when a second one of the two or more LCD areas transmits light.

In some embodiments, the controllable light source includes a light source **208** or **412-413-414** having two or more banks each having one or more LEDs and each operatively coupled to be activated by the electronic controller, wherein one or more of the banks can be simultaneously activated.

In some embodiments the first optical element is a ring reflector **432** situated to reflect only light from a first one of the banks **412**, and the second optical element is a ring reflector **433** situated to reflect only light from a second one of the banks **413**.

In some embodiments, the electronic controller **202** further selects a region of interest of an image, determines an image quality within the region of interest, and selectively controls the first and second light pattern based on the image quality.

Some embodiments further include a support station **450** (such as a conveyor belt) that supports an object being inspected by the machine vision system, and a selector **451** (see FIG. **4**) that rejects that object based on an analysis of the image.

Another aspect of the present invention provides an illumination method that includes emitting light, selectively polarizing the light, and selectively directing the light based on its polarization (see FIGS. **1**, **2**, and **3** above).

In some embodiments, the selectively directing provides two or more different angles of illumination (e.g., alpha and/or beta). In some such embodiments, the angle is a conical angle of a ring illumination.

In some embodiments, the selectively directing includes selectively reflecting based on polarization. In some embodiments, the selectively polarizing includes electronically driving a liquid-crystal device. In some such embodiments, the selectively directing further includes blocking light of one polarization and refracting light of another polarization (see, e.g., FIG. **3**).

Yet another aspect of the present invention provides a machine-vision method for inspecting an object. This method includes (a) setting one or more illumination parameters, (b) illuminating the object based on the one or more illumination parameters, (c) obtaining an image of the illuminated object, (d) generating a quality parameter based on an image quality of a predetermined region of interest in the image, and (e) iterating (b), (c), and (d) using a different illumination parameter.

In some embodiments of this method the iterating is based on the quality parameter. In some embodiments, the one or more illumination parameters include a predetermined azimuth angle of illumination. In some embodiments, the one or more illumination parameters include a predetermined compass angle of illumination. In some embodiments, the one or more illumination parameters include a predetermined compass angle of illumination. The embodiments described above are intended only to illustrate and teach one or more ways of practicing or implementing the present invention, not to restrict its breadth or scope. The actual scope of the invention, which embraces all ways of practicing or implementing the teachings of the invention, is defined only by the following claims and their equivalents.

What is claimed:

1. A computerized machine-vision method for inspecting an object, the method comprising:

illuminating the object based on a first set of obtained illumination parameters and obtaining a first image of the resulting illuminated object;

image processing a region of interest in the first image;

illuminating the object based on a different set of obtained illumination parameters and obtaining an additional image of the resulting illuminated object;

image processing a region of interest in the additional image; and

making a determination of a characteristic of the object based on at least one of the images.

2. The method of claim **1**, wherein the image processing a region of interest in the first image includes determining a quality parameter based on an image quality of the region of interest in the first image; and the image processing a region of interest in the additional image includes determining a quality parameter based on an image quality of the region of interest in the additional image.

3. The method of claim **2**, further comprising selecting one of the images based on a comparison of their respective quality parameters.

4. The method of claim **2**, further comprising iterating illuminating the object based on a different set of obtained illumination parameters and obtaining an additional image of the resulting illuminated object and image processing a region of interest in the additional image, wherein the iterating is based on a comparison of the quality parameter of the first image to the quality parameter of the additional image.

5. The method of claim **1**, wherein the illuminating of the object based on the first set of illumination parameters includes projecting light from a first LED and at a first azimuth angle toward the object while not projecting light from a second LED onto the object, and the illuminating of the object based on the different set of illumination parameters includes projecting light from the second LED and at a second azimuth angle toward the object while not projecting light from the first LED onto the object, wherein the first azimuth angle is not equal to the second azimuth angle.

6. The method of claim **1**, wherein the illuminating of the object based on the first set of illumination parameters includes projecting light from a first plurality of LEDs, each providing light at a first azimuth angle and at different compass angles, toward the object while not projecting light from a second plurality of LEDs onto the object, and the illuminating of the object based on the different set of illumination parameters includes projecting light from the second plurality of LEDs, each providing light at a second azimuth angle toward the object while not projecting light from the first plurality of LEDs onto the object, wherein the first azimuth angle is not equal to the second azimuth angle.

7. The method of claim **1**, wherein the illuminating of the object based on the first set of illumination parameters includes projecting light from a first LED and at a first compass angle toward the object while not projecting light from a second LED onto the object, and the illuminating of the object based on the different set of illumination parameters includes projecting light from the second LED and at a second compass angle toward the object while not projecting light from the first LED onto the object, wherein the first compass angle is not equal to the second compass angle.

8. The method of claim **1**, wherein the illuminating of the object based on the first set of illumination parameters includes projecting light from a first plurality of LEDs, each providing light at a first compass angle toward the object while not projecting light from a second plurality of LEDs onto the object, and the illuminating of the object based on the different set of illumination parameters includes projecting light from the second plurality of LEDs, each providing light at a second compass angle toward the object while not projecting light from the first plurality of LEDs onto the object, wherein the first azimuth angle is not equal to the second azimuth angle.

9. The method of claim **1**, wherein the at least one of the images is selected based on a quality parameter.

10. The method of claim **1**, wherein illuminating the object based on the different set of illumination parameters comprises changing at least one illumination angle of the object without physically changing optical components.

11. A machine-vision system comprising:

a processor operatively coupled to receive images from a camera and to generate a set of illumination-control parameters;

a light source operatively coupled to the processor and controlled by the processor to illuminate an object based on illumination-control parameters, wherein;

the processor is configured to analyze a first image captured by the camera,

control the light source to illuminate the object based on different illumination-control parameters,

analyze a second image captured by the camera, and

make a determination of a characteristic of the object based on at least one of the images and to output a signal based on the determination.

12. The system of claim **11**, wherein the processor is further configured to determine a first quality parameter based on an image quality of the region of interest in the first image; and to determine a second quality parameter based on an image quality of the region of interest in the additional image.

13. The system of claim **12**, wherein the processor is also configured to select one of the images based on a comparison of their respective quality parameters, and wherein the determination of a characteristic of the object is based on the selected one of the images.

14. The system of claim **12**, wherein the processor is also configured to iteratively change the light pattern, capture a further image of the object using the changed light pattern, and analyze the further image to determine its quality parameter, and to select between images based on a comparison of their respective quality parameters.

15. The system of claim **11**, wherein the light source includes a first LED and a second LED, and is configured to project light from the first LED and at a first azimuth angle toward the object while not projecting light from the second LED onto the object, and further configured to project light from the second LED and at a second azimuth angle toward the object while not projecting light from the first LED onto the object, wherein the first azimuth angle is not equal to the second azimuth angle.

16. The system of claim **11**, wherein the light source includes a first plurality of LEDs and a second plurality of LEDs, and is configured to project light from the first plurality of LEDs and at a first azimuth angle toward the object while not projecting light from the second plurality of LEDs onto the object, and further configured to project light from the second plurality of LEDs and at a second azimuth angle toward the object while not projecting light from the first plurality of LEDs onto the object, wherein the first azimuth angle is not equal to the second azimuth angle.

17. The system of claim **11**, wherein the light source includes a first LED and a second LED, and is configured to project light from the first LED and at a first compass angle toward the object while not projecting light from the second LED onto the object, and further configured to project light from the second LED and at a second compass angle toward the object while not projecting light from the first LED onto the object, wherein the first compass angle is not equal to the second compass angle.

18. The system of claim **11**, wherein the light source includes a first plurality of LEDs and a second plurality of LEDs, and is configured to project light from the first plurality of LEDs and at a first compass angle toward the object while not projecting light from the second plurality of LEDs onto the object, further configured to project light from the second plurality of LEDs and at a second compass angle toward the object while not projecting light from the first plurality of LEDs onto the object, wherein the first compass angle is not equal to the second compass angle.

19. The system of claim **11**, further comprising electrically controllable polarizers operably connected to the processor, wherein at least one angle of illumination of the object can be changed by the processor without physically changing any optical components.

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